CHAPTER 7

FIELD EXPERIMENTS AND BROADACRE FIELD TRIALS

7.1 General Introduction and Objectives

Earlier glasshouse experiments indicated that germination and early seedling growth were affected by differences between substrates and, to a lesser extent, by fertilizer and soil amendment treatments. A range of field experiments was established to examine further the effect of substrate and a variety of treatments and sowing times on germination and subsequent growth. Field experiments incorporated optimum fertilizer rates established in earlier glasshouse experiments together with a wider range of native species.

7.2 Field Experiment 1. Effect of Site Preparation and Mulch.

7.2.1 Introduction

Despite the almost universal acceptance of ripping and cultivation as techniques to relieve compaction and increase infiltration, a variety of studies, e.g. Pickersgill (1982), Tacey (1979), have reported few benefits in subsequent plant growth. The effect of deep ripping and cultivation on the germination of native trees has received scant attention in the literature.

Mulches, and particularly organic mulches, have been used to improve soil structure, microclimate, germination and plant growth. Agar (1984) showed that covering native tree seed with straw or chitter improved germination on topdressing at Hunter Valley No. 1 Mine. Other substrates were not tested.

Both mulches and site preparation techniques affect the physical environment of seed. The effects of these treatments, particularly on germination, may indicate means of improving germination and growth and define critical physical effects.

7.2.2 Objective

To examine the effects of three site preparation techniques and three mulches on germination and early growth for five species on three substrates at Hunter Valley No. 1 Mine.

7.2.3 Results

Relevant F values are shown in Appendix 2(viii).

The use of storm damage as a covariate did not explain additional variation in growth. Substrate had a highly significant effect on germination per cent and germination energy and a significant effect on the angular transformation of survival per cent (Table 7.1). Growth (average basal area and average height) of combined species on the three substrates was not significantly different after two years.

Both site preparation and mulch significantly affected germination per cent (Table 7.2). Germination energy and survival per cent were not significantly affected by any of the treatments. Neither of the growth parameters was significantly affected by site preparation or mulch treatments.

As expected, significant variations in germination per cent, germination energy, survival per cent, average height and average basal area occurred between species (Table 7.3). There were no interactions between species, substrate and treatments.

Figure 7.1 shows temperature readings at the surface and at 2 cm depth for Sandstone (2) and each mulch over a 3 hour period on November 20th, 1985.

Table 7.1 Effect of three substrates at Hunter Valley No. 1 Mine on germination per cent, germination energy and the angular transformation (arcsin) of survival per cent two years after sowing. Data are means for combined site preparation and mulch treatments and for combined species.

VARIABLE	SUBSTRATE		
	Topdressing (1)	Sandstone (2)	Shale (3)
Germ. %	0.74(B)	1.27(A)	0.96(AB)
Germ. energy	0.60(B)	1.03(A)	0.71(B)
Acrsin Surv. %	1.22(A)	0.79(B)	1.02(AB)

L S D's	Germ. % (Means of 27)	Germ. Energy (Means of 27)	Arcsin Surv. % (Means of 27)
$P \leq 0.05$	0.53	0.14	0.25
$P \leq 0.01$	0.80	0.20	N/S

Note: Values in the same row and with the same letter are not significantly different for $P \leq 0.05$.

Table 7.2 Effect of site preparation and mulch treatments on germination per cent, for combined substrates at Hunter Valley No. 1 Mine two years after sowing. Data are means for combined substrates and species.

	SITE PREPARATION		
	Deep Ripping	Cultivation	Control
	1.40(A)	0.73(B)	0.84(B)
	MULCH		
	Straw	Chitter	Control
	1.28(A)	1.05(A)	0.64(B)

L S D's	Site Prep. (Means of 27)	Mulch (Means of 27)
$P \leq 0.05$	0.49	0.36

Note: Values in the same row and with the same letter are not significantly different for $P \leq 0.05$.

Table 7.3 Germination per cent, germination energy, survival per cent, average height and average basal area for five native tree species two years after sowing. Data are means for combined substrates (Hunter Valley No. 1) and treatments.

VARIABLE	SPECIES				
	A. salicina	*C. glauca*	*E. cladocalyx*	*E. maculata*	*E.punctata*
Germ. %	15.3(A)	1.3(B)	2.3(B)	1.6(B)	1.7(B)
Germ. energy	0.71(A)	0.46(B)	0.79(A)	0.90(A)	0.71(A)
Surv. %	94.4(A)	94.2(A)	90.3(A)	70.5(B)	70.0(B)
Av. height (m)	1.01(B)	0.90(BC)	1.96(A)	0.94(B)	0.47(C)
Av.Basal Area (cm^2)	4.66(B)	1.25(BC)	21.00(A)	5.26(B)	0.01(C)
	(Means of 18)	(Means of 20)	(Means of 58)	(Means of 64)	(Means of 10)

Note: In each row, values with the same letter are not significantly different for $P \leq 0.05$

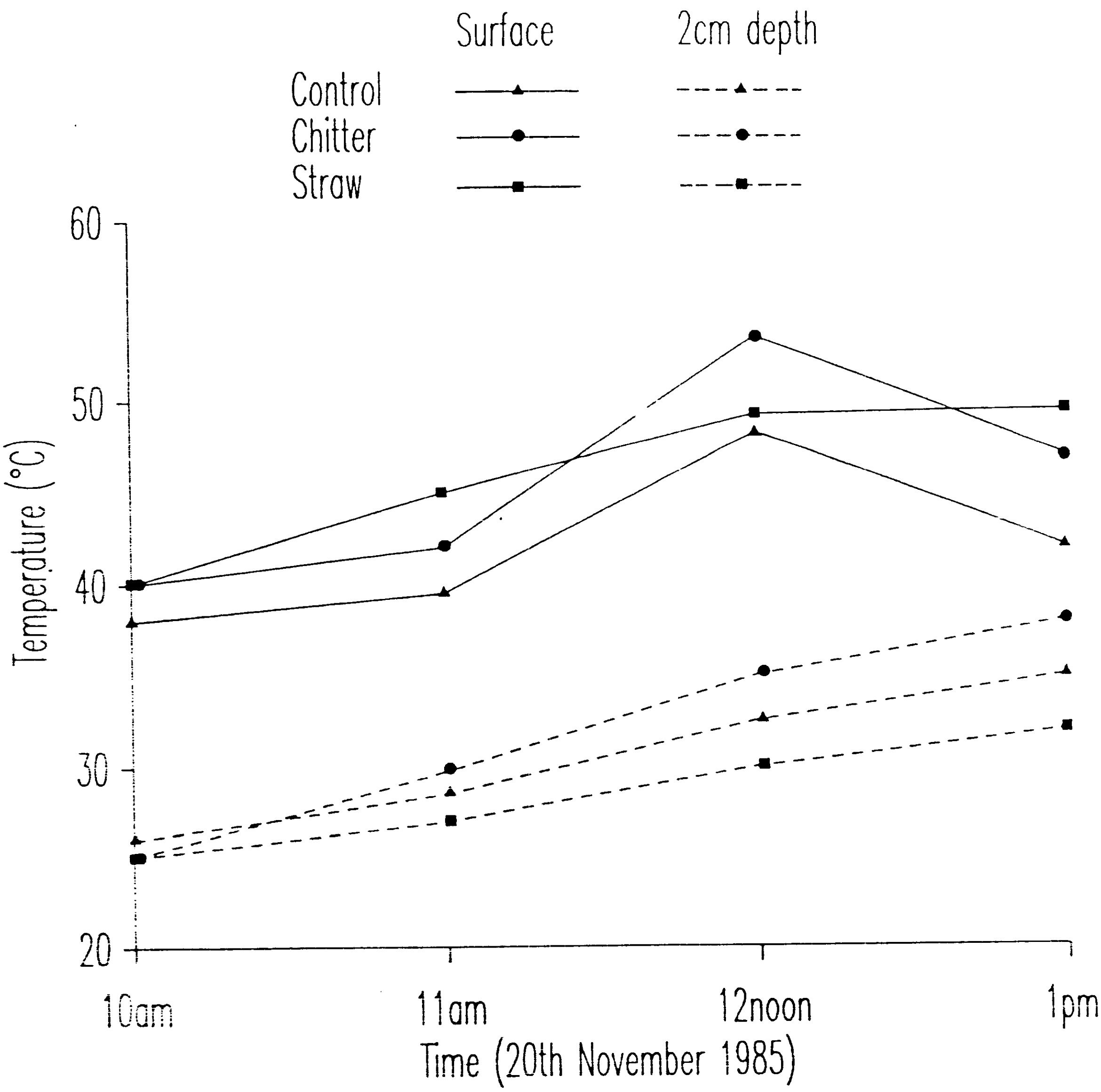

Figure 7.1 Temperature fluctuations at the surface and at 2 cm depth for three mulches on Sandstone (2) at Hunter Valley No. 1 Colliery during the period 10 a.m. to 1 p.m. on 20th November, 1985

7.2.4 Discussion

Germination per cent and germination energy showed similar substrate trends. This suggests that the mechanism affecting the number of germinants also affects the rate of seedling emergence. The inferior germination results for Topdressing (1) do not appear to relate to relative substrate moisture levels (Figure 5.1). The superior germination results for Sandstone (2) may reflect generally lower and less severe monthly (Figure 5.3) and daily (Figure 5.4) temperatures for this material. Figure 5.3 indicates that high maximum surface temperatures can exist during April and May (traditional sowing months). The reduction in both surface and below ground temperatures on Sandstone(2) may have a favourable effect on germination through either its effect on radicle emergence, or on pre-emergent survival. Other factors such as the depth of seed burial following rain may also be involved. The higher silt plus clay component on Topdressing (1) (Table 5.2) may result in more air-borne particles in raindrop splash and may result in a greater depth of seed burial for this material. Chemical factors (Table 5.1) do not appear to be involved. It is unlikely that biological factors, and particularly differences in damping-off, as discussed earlier are involved.

Figure 7.1 indicated that the chitter mulch resulted in higher subsurface temperatures than either straw or the control. Straw produced the lowest subsurface temperatures. These results were probably caused by the greater heat absorbing capacity of the dark, low albedo chitter and the insulating and greater reflective ability of straw. These opposing effects suggest that temperature differences were not a contributing factor in the favourable effect of straw and, to a lesser degree, chitter, on germination per cent. If temperature effects were critical, these affects should have resulted in differences in germination energy. The favourable effect of straw and chitter on germination per cent probably relates to enhanced moisture characteristics under the mulches due to increased infiltration and reduced evaporation (Doyle 1976). Mulch had no effect on germination energy.

The advantageous effect of deep ripping on germination per cent coincided with a strong concentration of seedlings in the rip lines. The concentration of seedlings in rip lines was also noted in broadacre sowing trials in this study. This suggested that either improved moisture availability, reduced wind exposure or decompaction, or improved seed retention on site were contributing factors. It was unlikely that site preparation techniques would have greatly affected near surface temperatures. The failure of cultivation to affect germination per cent suggests that decompaction within the root zone of new germinants was not a contributing factor. Improved moisture availability could also have been expected to affect survival and/or growth while reduced wind exposure should also have been reflected in increased survival. This was not the case.

Substrate survival trends differed from germination trends. This suggested that different controlling factors were involved. The higher survival of seedlings in Topdressing (1) (Table 7.1) coincided with the more favourable spoil water characteristics of this substrate (Figure 5.1).

None of the treatments affected survival. The absence of any improvements in survival by ripping or cultivating supports work by Pickersgill (1982) on rehabilitated bauxite mines. Growth was also unaffected by site preparation. As ripping can only be expected to give a positive growth response if compaction and infiltration are truly limiting (Rimmer 1979), it can be assumed that neither compaction nor infiltration were limiting in this experiment. This has broad implications for future tree establishment.

Assuming that cultivation is in effect, a shallow ripping then the results support the findings of Pickersgill (1982) and Tacey (1979), who both showed differences in ripping depth did not affect growth. The lack of any variation in growth between substrates varied markedly from earlier glasshouse results (e.g. glasshouse experiment 1) where seedling growth on topdressing material was greatly superior to seedling growth on other substrates, and where seedlings on these later substrates frequently exhibited deficiency symptoms. Amongst other things, the results suggest that differences in spoil moisture characteristics apparent in Figure 5.1, did not affect growth. Similarly, the expectation that site preparation (Bird 1982) and mulch techniques (Doyle 1976) would improve available moisture and hence growth, was not realized. It is reasonable to expect that any factor affecting survival would also affect growth. However, the favourable affect of Topdressing (1) on survival did not continue for growth. In the case of both survival and growth it must be recognized that topdressing material is only a thin surface veneer. After two years, the majority of a tree's roots could be expected to be located in lower substrate material. Consequently, the physical and chemical characteristics of this lower material would increasingly assert its effect on growth as the proportion of roots in this material increased. The degree to which underlying substrates affect growth would also be determined by the thickness of the topdressing material.

The absence of any variation in growth between substrates establishes a range of non-limiting physical and chemical values. Expansion of this range, using other substrates, should lead to a confirmation or refinement of limiting values suggested in Tables 5.1 and 5.2. The non-nutrient chemical characteristics of substrates used in this experiment fell within prescribed ranges. The similar substrate growth results tend to support the adequacy of the basal fertilizer dressing of 10 kg ha^{-1} each of N and P.

Differences in germination and survival between substrates could theoretically be offset by adjusting sowing rates. However, the inferior germination per cent of seedlings in Topdressing (1) was compensated for by superior survival. Resulting substrate stocking rates after two years were similar; Topdressing (1) = 1,925 trees ha^{-1}, Sandstone (2) = 2,222 trees ha^{-1}, Shale (3) = 2,148 trees ha^{-1}. All these rates were well above the current seedling planting rate of 420 trees ha^{-1} and suggest that sowing rates on all substrates could be reduced. There appears considerable scope for reducing the cost of applied seed below the current cost of \$520 ha^{-1}. However, as the seed mix includes both short-lived nurse and N-fixing species e.g wattles, as well as longer-lived *Casuarina* and *Eucalyptus* species, future stand dynamics, rather than just empirical stocking rates, must be considered.

Differences in germination per cent between treatments could also be offset by adjusting sowing rates. Improving the germination per cent of the control to that of the deep ripping treatment would cost an additional $347 (66% increase). As deep ripping only costs approximately $200 ha-1, deep ripping may be the more favourable economic option. Deep ripping along the contour also has erosion control benefits which may be more important in large scale native seed sowing in the absence of stabilizing pasture species.

Straw and chitter improved germination per cent by 100% and 64% respectively. Adjusting the sowing rates on the control to compensate for these differences would cost an additional $520 and $333 respectively. However, techniques for the large scale precise application of these mulches are not readily available. In addition, the cost and logistics of transporting and evenly applying these materials on a large scale are considered excessive and most likely to exceed the cost of heavier sowing rates.

Differences in germination between species were expected. Jacobs (1955) considered that the average 'tree per cent' (survival per cent) under normal forest conditions varied between 0.1 per cent for the small seeded eucalypt and 0.5 per cent for the larger seeded species. Using these figures, germination per cents, even after adjustment for survival per cent, were high, and germination and growth of each of the five native species after two years was considered adequate. Consequently, continued large scale use of all species was justified. The similarity in germination per cent and survival per cent of large seeded *E. maculata* and small seeded *E. punctata* suggested that seed size was not critical in this experiment. This disagreed with the findings or Irving (1987) who showed a positive linear correlation between seed size and survival of native tree species sown in conjunction with pasture at Tarong Mine in Queensland.

7.2.5 Summary

1. Substrate germination differences were apparent but there was no obvious physical or chemical spoil characteristic responsible.

2. Germination per cent was favourably affected by deep ripping. Other treatments had no effect.

3. Superior survival of seedlings in topdressing material probably related to the more favourable water characteristics of this substrate.

4. Unlike glasshouse experiments growth did not vary between substrates. This result indicates that glasshouse procedures substantially altered spoil physical and chemical characteristics.

5. The lack of field growth variation between substrates defines a range of non-limiting physical and/or chemical spoil characteristics.

7.3 Field Experiment 2. Effect of Soil Amendments.

7.3.1 Introduction

None of the soil amendments used in glasshouse experiment 2 improved germination per cent in that experiment. This was despite considerable differences in substrate surface crust strengths apparent in glasshouse experiment 3 (Figure 6.1). Terrasorb was the only soil amendment which improved germination energy. The effect on germination energy was broad and applied to both species and to all three substrates. Despite this, the improvement in subsequent growth was very specific and applied only to *E. maculata* on Topdressing (1). This result was considered to be an artefact of the experimental glasshouse design.

7.3.2 Objective

To examine the effect of three soil amendments, with one at two rates, on germination and early growth for five native species on three substrates at Hunter Valley No. 1 Mine.

7.3.3 Results

Relevant F values are shown in Appendix 2(ix).

The use of storm damage as a covariate did not explain additional variation in growth. Soil amendment treatments had no significant effect on any of the variables. As in field experiment 1 substrate had a highly significant effect on germination per cent and significant effects on germination energy and survival per cent. Unlike field experiment 1 substrate also had a significant effect on basal area, and a highly significant effect on average height two years after sowing (Table 7.4).

Between species there were significant variations in germination per cent, germination energy, survival per cent, average height and average basal area as found in field experiment 1. With the exception that no *E. punctata* germinated in this experiment, the relative order of species for each variable was the same as for field experiment 1. Consequently, the results have not been presented.

7.3.4 Discussion

The absence of any soil amendment effects supports the conclusion that the results of glasshouse experiment 2 were artefacts of

Table 7.4 Effect of three substrates at Hunter Valley No. 1 Mine on germination per cent, germination energy, survival per cent, average height and average basal area two years after sowing. Data are means for combined soil amendment treatments.

VARIABLE	SUBSTRATE		
	Topdressing (1)	Sandstone (2)	Shale (3)
Germ. %	0.16(B)	0.60(A)	0.45(A)
Germ. energy	0.19(B)	0.70(A)	0.81(A)
Surv. %	25.0(B)	83.1(A)	51.1(AB)
Av. height (m)	0.17(B)	0.94(A)	0.79(A)
Av. basal area (cm^2)	0.30(B)	7.47(A)	5.94(A)

L S D's	Germ.% (Mns.of12)	Germ. energy (Mns.of 12)	Surv. % (Mns.of12)	Av. ht. (Mns.of12)	Av. basal area (Mns.of 12)
$P \leq 0.05$	0.18	0.45	34.0	0.22	4.7
$P \leq 0.01$	0.27	N/S	N/S	0.34	N/S

Note: Values in the same row and with the same letter are not significantly different for $P \leq 0.05$.

the experimental glasshouse design. However, lack of control in field experiments may also be an important factor.

The effect of substrate on germination per cent and germination energy were similar to field experiment 1. However, for survival per cent the position of substrates was reversed with Sandstone (2) having superior survival and Topdressing (1) having inferior survival. These results may be confounded by the position of each experiment in the field (and hence altered physical conditions), or alternatively, the relatively low number of seedlings in this experiment (45) compared with field experiment 1 (170). The number of seedlings on Topdressing (1) (7) was considerably fewer than those on Shale (3) (16) and Sandstone (2) (22). The absence of substrate-induced growth effects is common to field experiments 1, 2, 3 and 5.

7.3.5 Summary

1. None of the soil amendments affected germination, survival or growth.

2. Substrate effect on survival varied from that observed in field experiment 1 on the same substrates.

7.4 Field Experiment 3. Effect of Fertilizer Applied in Loose and Pelletized Form.

7.4.1 Introduction

Glasshouse experiment 1 produced responses in both germination and growth of sown *E. maculata* and *C. glauca* seedlings to factorial combinations of N and P. Optimum growth response lay on a plateau between P10-P20 and N10-N20, although the results largely reflected the strong response of *E. maculata*.

Considerable work has recently been undertaken into the use of a wide variety of seed coatings and seed pellet formulations (Beswick and Moran 1985, Venning *et al.* 1985, Sharp 1985). While some researchers have reported outstanding success (Weatherby 1985), the overall results have been inconclusive. Pelletizing seed with fertilizer may result in greater fertilizer availability to the new germinant and help overcome rapid fixation of N and P apparent in Hunter Valley coal mine spoils (Elliott 1982).

7.4.2 Objectives

(1) To examine under field conditions the effect on germination, survival and growth of a range of species treated with two optimum rates of N and P (N10P10 and N20P20). The same three substrates from Hunter Valley No. 1 Mine used in glasshouse experiment 1 were repeated here.

(2) To examine the effect on germination, survival and growth of pelletizing seed with finely ground fertilizer at the same optimum rates of N and P as were applied loosely in (1) above.

(3) To compare the effect on germination, survival and growth of loosely applied and pelletized fertilizer.

7.4.3 Results

Relevant F values are shown in Appendix 2(x).

The use of storm damage as a covariate did not explain additional variation in growth.

The effect of substrate was much less pronounced than in field experiments 1 and 2. Substrate only had a significant effect on the transformed survival per cent (Table 7.5). All other variables were not

Table 7.5 Effect of fertilizer rate and three substrates at Hunter Valley No. 1 Colliery on transformed survival per cent two years after sowing. Data are means for combined method of application and species.

FERTILIZER RATE	SUBSTRATE			
	Topdressing(1)	Sandstone(2)	Shale(3)	Means(F)
N0P0	1.47	0.29	1.04	0.93(A)
N10P10	1.19	0.79	0.63	0.87(A)
N20P20	0.50	1.13	0.26	0.63(A)
Means (Sub.)	1.05(A)	0.74(AB)	0.64(B)	

L S D's	Means of Fert.	Means of Sub.	Substrate x Fertil. rate Table
	(Mns.of18)	(Mns.of18)	(Mns.of6)
$P \leq 0.05$	N/S	0.32	0.58
$P \leq 0.01$	N/S	N/S	0.78

Note: Values in the same row or column and with the same letter are not significantly different for $P \leq 0.05$.

affected by substrate. There was also a highly significant substrate x fertilizer rate interaction (Table 7.5) and a fertilizer rate x method of application interaction (Table 7.6) for transformed survival per cent.

Pelletizing seed had a highly significant effect on germination per cent with pelletized seed having inferior germination per cent (4.48%) compared to loosely applied fertilizer (6.25%). There was also a highly significant substrate x fertilizer rate interaction for germination per cent (Table 7.7).

Increasing fertilizer levels had no effect on growth parameters. Neither pelletized nor loosely applied fertilizer treatments when analysed separately or together had any significant effect on either growth parameter. As an example the average basal area of seedlings for treatments N0P0, N10P10 and N20P20 when combined over substrates was 9.9, 6.6 and 10.5 respectively with a LSD at the five per cent level of 8.9.

There were significant differences between species for germination energy, average height, transformed basal area and survival. These results were similar to those in glasshouse experiments 1 and 2 and are not presented here.

7.4.4 Discussion

Unlike field experiments 1 and 2, substrate had no effect on germination per cent or germination energy. This may be due to location, or reflect variation in physical and/or chemical characteristics of surface material. However, substrate differences did affect the transformed survival per cent in a similar manner to field experiment 1, with Topdressing (1) again giving superior survival. This result probably relates to the more favourable moisture characteristics of this material (Figure 5.1).

The interaction between substrate and fertilizer rate for survival was the result of seedlings in both Topdressing (1) and Shale

Table 7.6 Effect of method of fertilizer application and fertilizer rate on transformed survival per cent two years after sowing. Data are means for combined substrates and species.

Method of Fertilizer Application (M of A)	FERTILIZER RATE			Means (M of A)
	N0P0	N10P10	N20P20	
Loose	0.73	0.88	0.85	0.82(A)
Pelletized	1.14	0.86	0.41	0.80(A)
Means (Fert. Rate)	0.93(A)	0.87(A)	0.63(A)	

L S D	Means (Meth.of Applic.) (Mns. of 27)	Means Fert.Rate (Mns. of 18)	Method of applic.x Fert. Rate Table (Mns. of 9)
$P \leq 0.05$	0.27	0.34	0.47

Note: Values in the same row or columnm and with the same letter are not significantly different for $P \leq 0.05$.

Table 7.7 Effect of three substrates at Hunter Valley No. 1 Colliery and fertilizer rate on germination per cent two years after sowing. Data are means for combined method of application and combined species.

Fertilizer Rate	SUBSTRATE			
	Topdressing (1)	Sandstone (2)	Shale (3)	Means (Sub.)
N0P0	0.77	0.66	0.90	0.78(A)
N10P10	0.56	0.76	0.32	0.55(AB)
N20P20	0.43	0.65	0.36	0.48(B)
Means (Fert.)	0.58(A)	0.70(A)	0.53(A)	

L S D's rate	Means of Fert. (Mns.of18)	Means of Sub. (Mns.of18)	Substrate x Fert. (Mns.of 6)
$P \leq 0.05$	N/S	0.27	0.47
$P \leq 0.01$	N/S	0.36	0.63

Note: Values in the same row or column and with the same letter are not significantly different for $P \leq 0.05$.

(3) showing decreasing survival with increasing fertilizer rates, while seedlings in Sandstone (2) showed the reverse trend. These results parallel changes in root/shoot ratio observed in glasshouse experiment 1. In glasshouse experiment 1 the root/shoot ratio of seedlings in Sandstone (2) was considerably higher than the ratio for seedlings in the other two substrates. Increasing levels of N and P reduced the root/shoot ratio of seedlings in all three substrates in glasshouse experiment 1. The effect for *E. maculata* related to the stronger effect of increasing levels of N and P on shoot growth, as opposed to root growth. A reduction in root/shoot ratio with increasing fertilizer levels may have occurred in a similar manner in field experiment 3, leading to reduced field hardiness. The detrimental effect was more apparent for Topdressing (1) and Shale (3) which, glasshouse experiment 1 indicates, had lower initial ratios. Seedlings in Sandstone (2) in field experiment 3, with presumably higher initial root/shoot ratios, had more latitude for a reduction in root/shoot ratio without survival being affected. The fact that field survival actually increased with increasing N and P levels for seedlings in Sandstone (2) suggests that seedling vigour and rooting capacity was improved with increasing fertilizer levels. This is consistent with results in glasshouse experiment 1, where unfertilized seedlings in Sandstone (2) had low total weights and were often chlorotic. Glasshouse experiment 1 indicated that the effect on root/shoot ratio largely related to the effect on *E. maculata* and not *C. glauca*. The strong interaction in field experiment 3 suggests that other species (possibly the other two *Eucalyptus* species) may also have responded in a similar manner to *E. maculata*. From the results it is inferred that root/shoot ratio is a valuable guide to field hardiness and, as a corollary, there might exist a critical root/shoot ratio for each species or genus below which field survival is affected. The results testify to the value of root/shoot ratio as a guide to field hardiness and also the existence of a critical root/shoot ratio for a particular species or genus below which field survival is affected detrimentally.

The interaction between fertilizer rate and method of application for survival showed firstly that coating seed with gum arabic without adding fertilizer increased survival over non-coated seed. This may relate to the water absorbing capacity of gum arabic which may have assisted the early survival of new germinants. At N10P10 there was no difference in seedling survival between the pelletized and loosely applied fertilizer treatments. However, at N20P20 the close association of fertilizer with seed in pelletized form reduced survival by over 50%, compared to unpelletized seed. This effect may relate to a reduction in field survival due to an unfavourable increase in root/shoot ratio, or more likely to toxicity effects, due to excessive fertilizer in close proximity to seed.

Pelletizing seed also reduced germination per cent. Why this occurred is unclear, although the process of pelletizing may have encapsulated the seed with a physical barrier, thus restricting radicle emergence. Pre-emergent losses may also have occurred due to toxic fertilizer effects in a similar manner to the effect on survival and this effect may have been expressed in the results for germination per cent.

The interactive effect between substrate and fertilizer rate on germination per cent was similar to the same interaction for transformed survival per cent discussed earlier in this experiment. The similar results probably express the importance of differences in spoil moisture availability on both germination and survival. The effect of fertilizer on germination per cent agreed with the results for *E. maculata* in glasshouse experiment 1, which showed a general decrease in germination per cent with increasing rates of P. The effect was particularly pronounced for Topdressing (1) and Shale (3) in field experiment 3. The germination of seedlings on Sandstone (2) was not affected by increasing fertilizer rates. This may relate to the higher nutrient binding capacity of Sandstone (2) as reflected by a high pH (Table 5.1). N was shown to have little effect on germination per cent in glasshouse experiment 1.

The failure of applied fertilizer to affect growth differed from the results of glasshouse experiment 1, where strong growth responses, particularly for *E. maculata* were demonstrated with increasing rates of N and P. This result will be discussed later in Section 9.2.

7.4.5 Summary

1. The only advantage of fertilizer addition was an increase in survival of seedlings on Sandstone (2). The effect probably occurred through changes in plant root/shoot ratios.

2. Pelletizing seed with fertilizer either had no affect or decreased germination and survival.

3. Applied fertilizer in either form did not affect growth.

7.5 Field Experiment 4. Effect of Herbicide on Grass Competition

7.5.1 Introduction

Stabilizing recontoured spoil is an important, necessary and legislative requirement of mine rehabilitation. Under most circumstances, the best means of surface stabilization is through pasture establishment. However, this can create problems because native tree species have a poor ability to tolerate competition from exotic pasture species. This, combined with their consequent slow rate of stabilization compared to pasture species, has restricted the use of native tree species on some sites. Native tree species would be more widely used in mine rehabilitation if they could be established in conjunction with pasture. This may be achievable by either selecting less competitive pasture species or by the selective use of herbicides.

7.5.2 Objective

To examine the effect of six pasture swards of varying composition in conjunction with the use of one knockdown and one pre-emergent herbicide on the germination and early growth of five native tree species on Topdressing (1) at Hunter Valley No. 1 Mine.

7.5.3 Results

Due to below average rainfall following sowing in April, 1986 (Table 3.3), germination of sown native tree seed was negligible. This effect was also accentuated by the "swamping" effect of weeds and sown pasture after rain occurred, and the relatively low germination per cent observed on Topdressing (1) at Hunter Valley No. 1 Mine in field experiments 1, 2 and 3. Consequently, no germination or growth data were available for native tree species. Despite this, temperature and gravimetric spoil moisture was measured weekly for the 12 month period after sowing in April, 1986, and results were averaged for each pasture type (Table 7.8). Per cent ground cover was measured 12 months after sowing (Table 7.8).

7.5.4 Discussion

The failure of significant numbers of native seeds to germinate and survive emphasizes the dependence of direct seeding of native species on adequate follow-up rainfall. In contrast, seedlings planted on adjacent spoil over the autumn and winter of 1986 survived and grew well. Most planted seedlings received no artificial watering, although watering of individual seedlings can be readily undertaken. It is not considered practical, in terms of cost and the quantity of water required, to artificially water substantial areas of directly sown seed.

All pasture swards reduced the temperature at the surface and at 2 cm depth. The maximum reduction at both levels occurred under the standard Soil Conservation Services (S.C.S.) pasture mix. This pasture type also had the highest total ground cover per cent after 12 months and lower spoil temperatures were obviously a direct consequence of the degree of shading. Average temperatures under pasture swards were considered adequate for germination of most native species. However, it is possible that the shading effect of pasture cover may reduce temperatures below critical germination temperatures in winter. The standard S.C.S. pasture mix also had the highest average gravimetric water content. The control had one of the lowest average gravimetric water contents. However,

Table 7.8 Average spoil temperature, gravimetric moisture content and per cent ground cover, measured for five different pasture swards on Topdressing (1) at Hunter Valley No. 1 Mine.

VARIABLE		PASTURE					
		Control	Oats	S.C.S. Mix***	Phalaris	Tree Mix	Legume
Ave. Temp* (°C)	Surface	26.6	25.3	24.8	24.9	25.6	25.3
	2 cm depth	22.0	21.1	20.8	21.5	21.3	21.4
Ave.Grav.H_2O* %		6.63	6.30	7.34	6.60	6.94	7.10
Ground Cover % **	Alive	0	1.7	17.0	1.0	6.7	0
	Dead	9.0	38.3	40.6	36.3	50.7	22.0
	Total	9.0	40.0	57.6	37.3	57.4	22.0

* Measured weekly and averaged over 12 months following sowing of native tree seed in April, 1986.

** Measured 12 months after sowing.

*** Standard Soil Conservation Service autumn pasture recommendation.

differences were not great and may not be important. It is possible that at certain times of the year pasture cover may reduce wind velocity and hence reduce evaporation from the underlying substrate. Such a reduction could result in a net increase in similar spoil moisture when compared to the control. This would most likely occur when pasture had died or stopped active growth as a result of frost, drought or herbicide application. Despite the higher spoil moisture levels in pasture when compared to the control in this experiment it is likely that competition for moisture during periods of active pasture growth may still affect native plant survival and growth. This study did not indicate if or when this may occur.

7.5.5 Summary

1. The failure of significant numbers of native tree seeds to germinate and survive was a consequence of inadequate follow-up rainfall and the "swamping" effect of sown pasture species.

2. Pasture swards generally reduced surface and sub-surface temperatures.

7.6 Field Experiment 5. Effect of Month of Sowing.

7.6.1 Introduction

Agricultural experience within the Hunter Valley has shown that successful crop development can be very dependent on season of sowing. In mine revegetation, most mining companies in the upper Hunter Valley sow pasture in autumn, spring sowing being more prone to unfavourable temperatures (Table 3.2) and higher evaporation (Table 3.5) during the more sensitive first months of growth. Ideally, optimum sowing time should coincide with adequate temperature and moisture conditions for both germination and early growth. The importance of spoil moisture

(Hannan 1979b, Kelly 1979) and spoil temperature (Shirts and Bilbury 1976) on mine revegetation is well documented. Differences in substrate moisture (Figure 5.1) and temperature (Figure 5.3) characteristics can be substantial and may effect germination and/or early growth.

7.6.2 Objective

To examine the effect of month of sowing on germination and early growth during a six month period (between April and September, inclusive 1986) for five species and three substrates at Hunter Valley No. 1 Mine.

7.6.3 Results

Relevant F values are shown in Appendix 2(xii).

Germination per cent was not significantly affected by either substrate differences or month of sowing. Despite this, the germination per cent for May was approximately half that of most other months (Table 7.9).

Species effects were significant at the five per cent level and the germination per cent for species in declining order were *A. salicina* (23.5%), *E. maculata* (1.26%), *E. cladocalyx* (0.94%), *C. glauca* and *E. punctata* (no germination).

Germination energy was not significantly affected by substrate but was significantly affected by the month of sowing (Table 7.9). Survival per cent was not affected by substrate, month of sowing or species.

Both average height and average basal area were not significantly affected by substrate at the five per cent level but were at the ten per cent level (Table 7.10). Month of sowing had no

Table 7.9 Effect of month of sowing on germination per cent and germination energy. Data are means for combined substrates (at Hunter Valley No. 1 Mine) and combined species.

Month of Sowing	VARIABLE	
	Germination %	Germination Energy
Apr. (means of 12)	0.34(A)	0.79(AB)
May (means of 11)	0.22(A)	0.49(B)
Jun. (means of 11)	0.42(A)	0.81(AB)
Jul. (means of 12)	0.44(A)	1.00(AB)
Aug. (means of 11)	0.48(A)	1.06(AB)
Sept.(means of 9)	0.44(A)	1.58(A)
L S D's	Germ. % (Mns.of 9)	Germ. energy (Mns. of 9)
$P \leq 0.05$	N/S	0.98

Note: Values in the same column and with the same letter are not significantly different for $P \leq 0.05$.

Table 7.10 Effect of three substrates at Hunter Valley No. 1 Mine on average basal area and average height. Data are means for combined month of sowing and combined species.

VARIABLE	SUBSTRATE		
	Topdressing (1)	Sandstone (2)	Shale (3)
Ave. Height (m)	0.20(A)	0.11(B)	0.13(AB)
Ave. Basal Area (m^2/ha)	0.22(A)	0.06(B)	0.11(AB)

L S D's	Ave. Height (Mns. of 18)	Ave. Basal Area (Mns. of 18)
$P \leq 0.10$	0.09	0.11

Note: Values in the same row and with the same letter are not significantly different for $P \leq 0.10$.

significant effect on either growth variable. Both average height and average basal area varied between species. The results were generally consistent with species results shown in field experiment 1 (Table 7.3).

Weekly gravimetric water contents were taken for all three substrates over the duration of this experiment and averaged on a monthly basis (Table 7.11). These results were not statistically analysed but do provide a comparative estimate of gravimetric water content for each month. Temperature fluctuations for each substrate are shown in Figures 5.3 and 5.4.

7.6.4 Discussion

The variable effect of substrate on germination, survival and growth, apparent in earlier field experiments, was again evident. This variability between experiments suggests that the nature of surface material varies within each substrate type, or that there may be some interaction between substrate and rainfall or temperature following sowing. Figures 5.1 and 5.3 indicate that differences in substrate moisture and temperature levels do exist. Figure 5.3 also indicates that temperature differences are greater at certain times of the year. These effects may be further complicated by aspect or the relative position of each experiment on the slope. Species affects may also vary with season and/or changes in seed viability. As an example, field experiment 5 was sown approximately 12 months after field experiments 1, 2 and 3. Subsequent weather conditions varied. The superior growth of seedlings on Topdressing (1) and the inferior growth on Sandstone (2) in this experiment agrees with relative substrate moisture characteristics shown in Figure 5.1 However, growth responses in this experiment (Table 7.10) vary from those in field experiment 2 (Table 7.4). As conditions in 1986 were much drier over most of the year than in 1985 (Table 3.5) it is likely that differences in substrate moisture characteristics were more critical and assertive in their effect on growth in 1986 than in the wetter year.

Table 7.11 Average monthly substrate moisture percentages. Data are means for combined substrates and combined species at Hunter Valley No. 1 Mine.

MONTH #	YEAR	AVERAGE MONTHLY GRAV. WATER %*	ACTUAL RAINFALL** (mm)
Apr. #	1986	4.6	2
May #		8.9	23
Jun. #		4.7	12
Jul. #		12.8	36
Aug. #		11.3	74
Sep. #		9.9	77
Oct.		7.9	33
Nov.		7.2	105
Dec.		3.5	12
Jan.	1987	2.9	102
Feb.		2.8	5
Mar.		5.2	102

* Weekly readings averaged for each month over the three substrates. Samples taken simultaneously from substrates.

** After Hunter Valley No. 1.

\# Seed sown on the first day of each month.

Stocking densities at the end of this experiment were lower than those for field experiment 1. This undoubtedly related to drier conditions experienced after sowing in most months in 1986 and further evident in field experiment 4. Although survival was not significantly affected by substrate, the stocking density (surviving seedlings per hectare) was lower and also varied more than those in field experiment 1. Sandstone (2) had the highest stocking density (1,555 stems ha^{-1}), followed by Topdressing (1) (1,111 stems ha^{-1}) and Shale (3) (1,000 stems ha^{-1}). However, relative stocking densities did not correspond to relative substrate growth levels shown in Table 7.10. This suggests that substrate moisture characteristics, which appeared to affect growth, were not a critical factor in germination and survival.

Despite the dry conditions, stocking densities were still acceptable and over twice the density of traditionally planted seedlings. Obtaining adequate stocking levels in below average rainfall conditions validates the larger scale use of native species in direct seeding in coal mine revegetation in the Hunter Valley. These results suggest that the general failure of native tree species to establish in field experiment 4 may not have exclusively related to dry conditions.

The absence of any significant effect of month of sowing on germination per cent, survival per cent and growth suggests that sowing can be successfully undertaken between April and September. These months generally had higher gravimetric water per cent despite receiving generally less rainfall than warmer months (Table 7.11), and extension of sowing outside this range may prove unsuccessful. However, care must be taken in drawing conclusions from this experiment. Ideally, this experiment should be expanded into other months and repeated over a number of years, and long term results averaged. This would provide a more accurate prediction of success in any particular month. Indeed, repetition of field experiments generally over time would give more meaningful results.

Germination energy was the only variable affected by varying the month of sowing. Germination energy improved between May and

September and probably reflected successive increasing temperature in the six months following each sowing event. However, as increasing the rate of germination (germination energy) did not effectively result in higher germination per cent or better survival or growth a higher germination energy in this case confers little advantage.

7.6.5 Summary

1. The variable and inconsistent effect of substrate on field germination, survival and growth was again evident.

2. Dry conditions after sowing adversely affected stocking densities after 12 months. Despite this, stocking densities were still adequate.

3. There was no obviously superior month for sowing was evident from the experiment.

7.7 Field Experiment 7. Japanese Millet Competition Experiment.

7.7.1 Introduction

Irrespective of the techniques used to establish shrub and tree species, their growth rate is such that they provide little protection for the surface of the landscape against erosion, particularly on sloping ground. In such cases, temporary cover crops may be required to achieve erosion control but still allow the native plants to establish and eventually develop a more stable ecosystem. In other instances, where water erosion is not a problem, pasture crops may still be required to provide direct protection for native seedlings from extreme temperatures or wind blasting.

All plants, whether they be native species or introduced grasses, need an adequate supply of light, water and nutrients. Joint planting or sowing of native species and cover crops poses the dilemma of achieving erosion control without affecting native species development. The failure of native tree species in field experiment 4 led to establishment of a similar experiment in a higher rainfall area in the lower Hunter Valley.

7.7.2 Objective

To examine the effect of five rates of Japanese Millet on the germination and early growth of five native tree species, sown in conjunction, on two substrates at Bloomfield Colliery in the lower Hunter Valley.

7.7.3 Results

Relevant F values are shown in Appendix (xiii).

Japanese millet germinated and grew more readily on Topdressing (19) than on Overburden (20) (Table 7.12). At the time of measurement (12 months), most of the millet on both substrates had died.

Germination per cent did not vary significantly between substrates at the five per cent level. Despite this, germination per cent for Topdressing (19) was 37% less than for Overburden (20) (Table 7.13). The rate of Japanese millet applied did not significantly affect germination per cent of native species, although there was a substantial increase in germination per cent at most applied rates of Japanese millet (Table 7.12). The effect was most pronounced for Topdressing (19). Germination per cent varied between species with *A. longifolia* (34%) being superior to *E. punctata* (21%) which was superior to *A. costata* (4%) and *E. maculata* (5%). *C. glauca* had the poorest germination per cent (0.4%).

Germination energy was significantly affected by substrate (Table 7.13) but not by millet rate, although there was a substantial

Table 7.12 Effect of five rates of Japanese millet on germination per cent and germination energy of native tree species for two substrates at Bloomfield Colliery in the lower Hunter Valley. Data are means for combined species.

VARIABLE	Substrate	RATE-JAPANESE MILLET (kg ha^{-1})				
		0	2.5	5	10	20
Germination * %	Topdressing (19)	0.57	2.12	1.84	1.41	2.83
Germination * energy		0.44	2.25	2.51	1.53	1.40
Ave. ground cover % for millet (12 months after sowing)		0	10	12	19	30
Germination * %	Overburden (20)	2.34	3.40	4.31	1.49	2.40
Germination * energy		6.16	2.76	2.60	8.63	6.54
Ave.ground cover % for millet (12 months after sowing)		0	4	5	3	2

* No effects significant.

Table 7.13 Effect of two substrates at Bloomfield Colliery on germination per cent, germination energy and survival per cent. Data are means for combined rates of Japanese millet and tree species.

VARIABLE	SUBSTRATE	
	Topdressing (19)	Overburden (20)
Germination %	1.75(A)	2.79(A)
Germination energy	1.63(B)	5.34(A)
Survival %	75.30(A)	54.5(B)

L S D's	Germ % (Mns.of 15)	Germ. energy (Mns.of 15)	Surv. % (Mns.of 15)
$P \leq 0.05$	N/S	2.37	10.75
$P \leq 0.01$	N/S	N/S	17.83

Note: Values in the same row and with the same letter are not significantly different for $P \leq 0.05$.

increase in germination energy at higher millet rates (Table 7.12). The effect was more pronounced for Topdressing (19). Germination energy was not affected by species.

Substrate had a highly significant effect on survival per cent (Table 7.13). Millet sowing rate and species had no significant effect on survival per cent.

There was a significant quadratic response by both average tree height and average basal area to increasing millet rates. This result was very similar in both cases and only the result for average height is shown (Figure 7.2). This result was more pronounced for Topdressing (19). Despite a significant difference in germination energy between substrates observed earlier, neither average height nor average basal area were significantly affected by substrate.

As expected, both average height and average basal area varied significantly between species. For both variables *E. maculata* was superior to *E. punctata, A. costata* and *A. longifolia* which were superior to *C. glauca.*

The results of daily gravimetric moisture measurements for each rate of Japanese millet over a 15 day period (May 29th, to June 12th, 1986) for Topdressing (19) are shown in Figure 7.3.

7.7.4 Discussion

The lower germination per cent for Topdressing (19) was generally consistent with inferior germination per cents on topdressing material at Hunter Valley No. 1 Mine observed in previous field experiments. Relative germination levels did not parallel relative substrate moisture availability in any of the field experiments. This suggested that some factor other than substrate moisture availability affected germination per cent. Differences could not be linked with any of the measured chemical or physical characteristics. However, it was

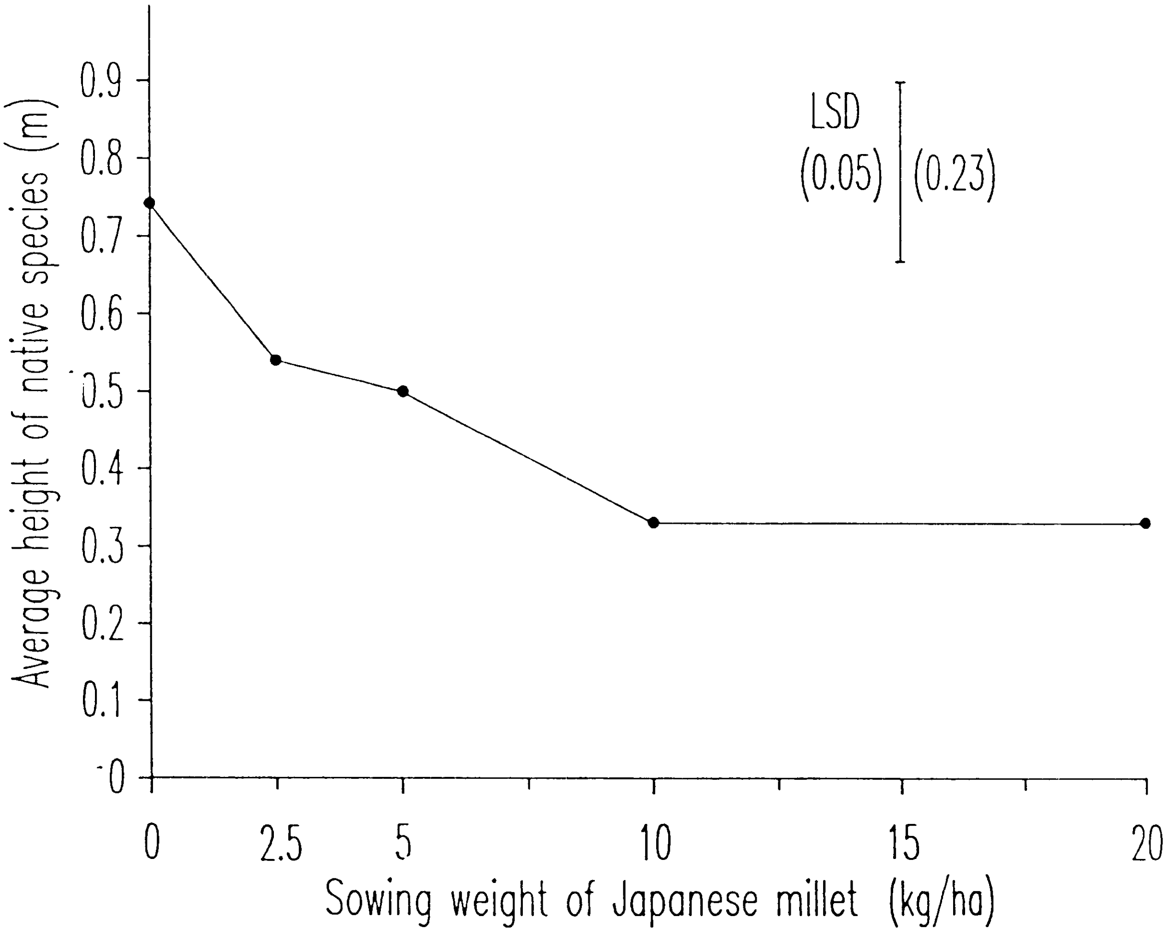

Figure 7.2 **Effect of increasing sowing rates of Japanese millet on average height of native tree species 12 months after sowing.**

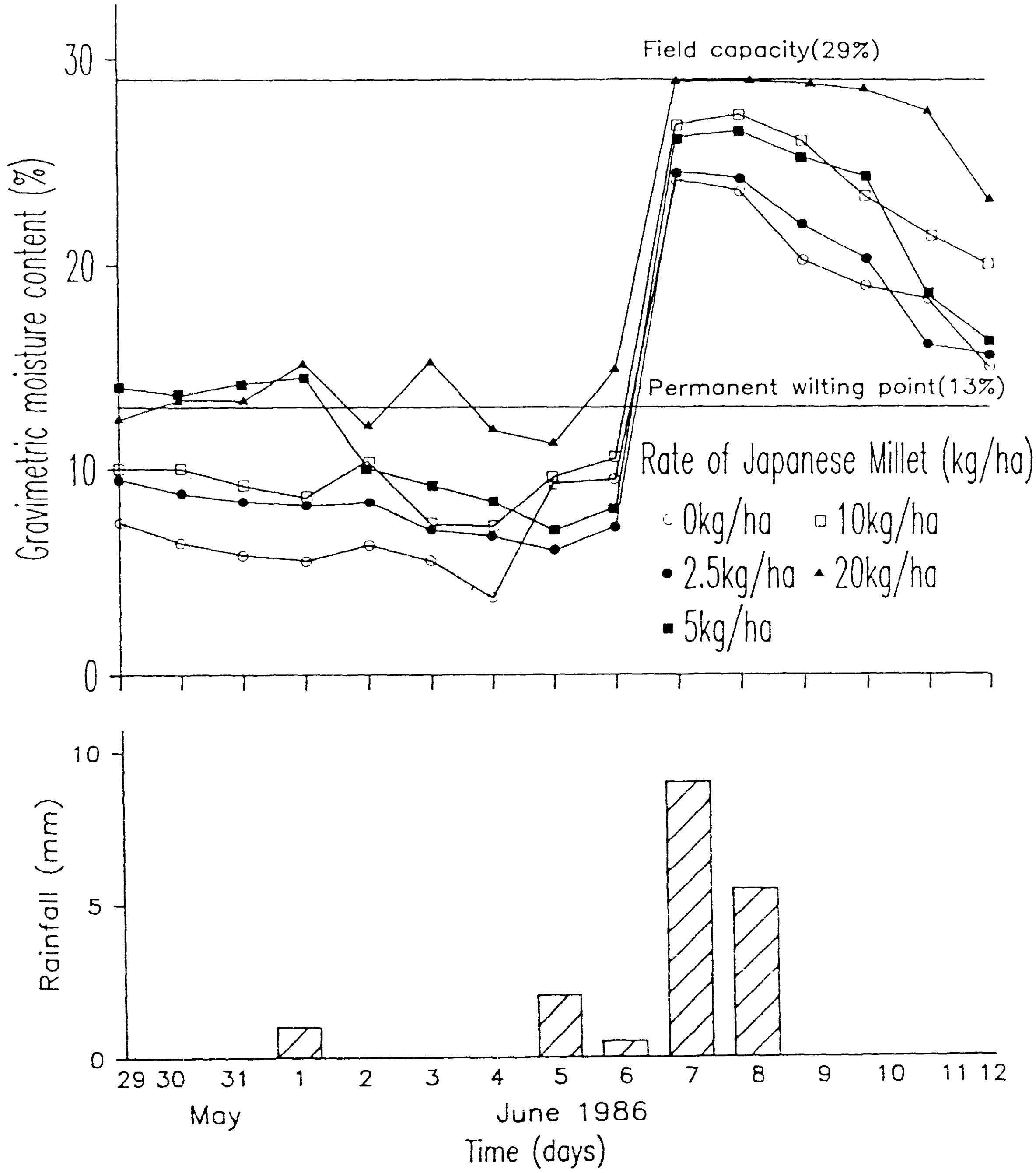

Figure 7.3 Spoil gravimetric moisture contents measured over a 15 day period between 29th May and 12th June, 1986, for five rates of Japanese millet on Topdressing (19) at Bloomfield Colliery in the lower Hunter Valley

suspected that native seed on topdressing material was being buried at greater depths than on other substrates following rain. As the success of emergence of native seed can be greatly affected by the depth of burial (Agar 1984, Free 1951), a greater depth of seed cover would reduce germination per cent. The effect may relate to textural differences and, particularly, the higher clay content of topdressing materials at Bloomfield and at Hunter Valley No. 1 Mines. Many topdressing materials are also more dispersible than other mine substrates (Gordon 1987) and this may result in greater depth of seed cover.

Despite inferior germination per cent for Topdressing (19), superior survival of seedlings in this material resulted in more stems per hectare after twelve months (2,930 stems ha-1) than on Overburden (20) (2,470 stems ha -1). These results could not be related to chemical characteristics and the better moisture characteristics of Overburden (20) (Figure 5.2) was contrary to the survival trend. Superior survival of native species on Topdressing (19) may relate to the better establishment of Japanese millet on this material. Figure 7.3 shows increasing gravimetric water content with increasing sowing rates of Japanese Millet. This result is in agreement with results in field experiment 4 where higher ground cover per cent was related to higher gravimetric water content to a depth of 2 cm. These results suggest that in some circumstances increased ground cover may reduce evaporation losses from spoil. This effect may be exaggerated by the elevated, exposed nature of many reshaped spoil heaps. Consequently, the higher levels of Japanese Millet on Topdressing (19) resulted in reduced wind exposure, higher gravimetric moisture levels and, in turn, superior survival per cent and germination energy of native species compared to Overburden (20). This effect did not extend to growth, and neither average height nor average basal area was significantly affected by substrate. It is inferred that physical and chemical substrate differences were not critical to growth up to 12 months. This was not unexpected as there was little difference between substrate chemical characteristics and particle size composition. The superior spoil moisture characteristics of Overburden (20) (Figure 5.2) apparently conferred no growth advantage.

The effect of Japanese millet on the establishment of native species was less pronounced than substrate effects. Germination energy and germination per cent were not significantly affected by millet sowing rates, although there was a substantial improvement in both variables at higher millet rates, particularly on Topdressing (19). This result further supports the "nurse crop" effect of Japanese millet discussed earlier. Despite the possible benefit of Japanese millet to germination, both average height and average basal area decreased with increasing rates of Japanese millet. This response was very pronounced and consistent and was opposed by the apparent increase in gravimetric water levels associated with increasing millet sowing rates. The decline in growth may reflect increased competition for soil nutrients and particularly soil N as proposed by Richards (1967). Competition for light was not considered an important factor due to the low height and comparatively low ground cover density of the millet. The decline in tree growth with increasing millet sowing rates was more pronounced for Topdressing (19), probably reflecting higher millet cover. However, the effect was also apparent for Overburden (20). This suggests that very low levels of millet, as shown in Table 7.12, have the ability to affect the growth of native species detrimentally.

Germination and survival was higher at Bloomfield Mine in the lower Hunter Valley, than at Hunter Valley No. 1 Mine in the upper Hunter Valley. The result probably reflects higher rainfall conditions in the lower Hunter Valley (Table 3.1). All species tested produced acceptable levels of germination and appeared suitable for large scale use.

7.7.5 Summary

1. Japanese millet had no effect on the germination of native tree species.

2. Increasing rates of Japanese millet reduced native tree growth.

7.8 Broadacre Field Trials

7.8.1 Introduction

Following successful germination and growth of a range of native tree species on a range of different substrates in small scale field experiments, there was a strong need to demonstrate techniques on a larger scale. This action was prompted by the need to confirm earlier glasshouse experimental results in the field, to examine further substrate physical and chemical effects, and to provide large scale demonstration areas for the coal mining industry.

7.8.2 Broadacre Field Trial 1. Bloomfield Colliery

7.8.2.1 Objectives

(1) To examine germination and early growth of five directly sown native tree species on two substrates at Bloomfield Colliery in a similar manner to field experiment 7, but on a larger scale and without Japanese millet.

(2) To examine the effect on early growth of dibbled seedlings as opposed to directly sown seedlings on two substrates at Bloomfield Colliery.

(3) To examine the cost and efficacy of establishment techniques.

7.8.2.2. Results

Plates 7.1 and 7.2 show Topdressing (19) and Overburden (20) 22 months after sowing.

Plate 7.1 Directly sown native tree species growing on Topdressing (19) at Bloomfield Colliery 22 months after sowing.

Plate 7.2 Directly sown native tree species growing on Overburden (20) at Bloomfield Colliery 22 months after sowing.

Values for germination per cent and trees per hectare for Overburden (20) were almost three times those for Topdressing (19) (Table 7.14). However, the average height of seedlings on Topdressing (19) was superior to that for seedlings on Overburden (20) for both sown and planted seedlings (Table 7.14). The average height of individual species for each substrate and each method of establishment were compared (Table 7.14). These results also permit a comparison of average heights between direct sown and planted seedlings. For comparable species, the average height of planted seedlings was always greater than the average height of sown seedlings for each substrate, but the difference was not statistically significant at the five per cent level for *E. punctata* on Overburden (20), nor for *E. maculata* on Topdressing (19).

7.8.2.3 Discussion

The superior germination per cent of seedlings on Overburden (20) was much more pronounced than in adjacent field experiment 7. This effect may relate to either changes in substrate characteristics, differences in method of seed application or some ameliorating effect relating to the use of Japanese millet in field experiment 7. The average height of directly sown seedlings for combined substrates was 33% greater for broadacre field trial 1 than for the control in field experiment 7. Both were sown and measured at the same time. Taller seedlings may also be the indirect result of high stocking rates resulting in more rapid height growth due to increased competition for light. The effect may also relate to earlier explanations or may express a sheltering effect resulting from larger numbers of seedlings in the field trial and similar to that proposed for Japanese millet in field experiment 7, i.e. in the early stages of growth larger numbers of seedlings provide a more sheltered environment for individual plants, leading to better individual growth.

Despite the absence of any effect of substrate on average height in field experiment 7, sown seedlings on Topdressing (19) in broadacre field trial 1 were 2.5 times taller than seedlings on Overburden (20). This effect did not appear to relate to better chemical

Table 7.14 Effect of two substrates at Bloomfield Colliery on stocking rate, composition per cent, average height (m), germination per cent and survival per cent for five native tree species 12 months after sowing or planting.

Method of Establishment	Species	Stocking rate (Trees ha^{-1})	% Composition	Av. Height(m)±SE	Germination %	Survival %
			TOPDRESSING (19)			
SOWN	*A. longifolia*	6,000	43.9	0.64(B)±0.07	23.7	Not Measured
	A. costata	1,667	12.2	0.52(B)±0.06	2.5	
	C. glauca	0	0	0.00	0	
	E. maculata	6,000	43.9	1.26(A)±0.13	4.2	
	E. punctata	0	0	0.00	0	
	TOTAL/AVERAGE	13,667	100.0	0.90 ±0.08	2.8	
PLANTED	*A. longifolia*	57	17	1.44(B)±0.09	N/A	68
	A. costata	63	18	0.69(C)±0.03		72
	C. glauca	81	23	1.61(B)±0.07		92
	E. maculata	77	22	1.49(B)±0.07		88
	E. punctata	70	20	2.20(A)±0.11		80
	TOTAL/AVERAGE	348	100	1.51 ±0.06		80
			OVERBURDEN (20)			
SOWN	*A. longifolia*	11,333	29.3	0.32(A)±0.04	44.8	Not Measured
	A. costata	5,000	12.9	0.27(A)±0.04	7.6	
	C. glauca	0	0	0.00	0	
	E. maculata	20,667	53.4	0.38(A)±0.04	14.5	
	E. punctata	1,667	4.4	0.56(A)±0.13	23.8	
	TOTAL/AVERAGE	38,667	100.0	0.35 ±0.02	7.9	
PLANTED	*A. longifolia*	57	21	1.21(B)±0.09	N/A	68
	A. costata	18	6	0.38(D)±0.02		20
	C. glauca	53	19	0.75(C)±0.15		60
	E. maculata	77	27	1.58(A)±0.11		88
	E. punctata	77	27	0.81(C)±0.11		88
	TOTAL/AVERAGE	282	100	1.07 ±0.07		65

Note : (1) Height values within particular methods of establishment and with the same letter are not significantly different for $P \leq 0.05$.
(2) N/A = Not applicable.

(Table 5.1) or physical (Table 5.2, Figure 5.2) characteristics for Topdressing (19). Table 5.1 indicated that Overburden (20) generally had superior nutrient levels than Topdressing (19). The effect most likely relates to reduced competition for moisture or nutrients on Topdressing (19) due to a lower stocking density.

Differences in height between sown and planted seedlings were expected due to the initial height advantage of planted seedlings. However, the extent of this difference varied between substrates. Planted seedlings (combined species) were 66% taller than sown seedlings on Topdressing (19) after 12 months. However, the difference was even more dramatic for Overburden (20) where planted seedlings were 200% taller. This result probably reflects stronger competition between sown seedlings for moisture or nutrients due to higher stocking rates. For some species e.g. *E. maculata*, the difference in height between sown and planted trees was minimal. Stocking rates on sown areas were well above both initial planted seedling densities of 420 trees per hectare and acceptable native forest stocking rates proposed by Jacobs (1955) of 1,000 trees per hectare. Stocking rates at Bloomfield were also between 2 and 7 times those of similar trials in the upper Hunter Valley (Table 7.15) and probably reflect more reliable and heavier rainfall in the Lower Hunter Valley rather than superior substrate characteristics. However, if timber production is not an objective, higher stocking rates can provide quicker canopy closure leading to reduced raindrop impact and erosion. In addition, the high proportion of *A. longifolia* on both Topdressing (19) (44%) and Overburden (20 (29%) will result in a substantial contribution of organic material and spoil N (Langkamp *et al.* 1982). The taller *Eucalyptus* seedlings on both substrates suggests that the high stocking rate of *A. longifolia* is not prejudicing *Eucalyptus* growth after 12 months. The author's experience in commercial forest *Eucalyptus* plantations suggests that once *Eucalyptus* seedlings close canopy, most underlying wattles will die out due to reduced light. This will result in a substantial reduction in trees per hectare. Despite the above it was also apparent that after 12 months many *Eucalyptus* seedlings were suppressed. Further study of stand development will be necessary to determine whether the demand by surviving seedlings on spoil resources, particularly moisture and nutrients, will retard growth of dominant trees in the stand. If so, a reduction and/or alteration of sowing rates and species composition may be required.

The failure of *C. glauca* to germinate on both substrates and the failure of *E. punctata* on Topdressing (19) varies from other results at nearby mines and cannot be explained. There is obviously some effect of substrate on species, but the particular limiting spoil characteristics were not identified.

The cost per hectare for direct sown seedlings was $500 (3.8 kg ha-1). This compared to $1,344 ha-1 for planted seedlings (420 trees ha-1). The cost advantage of direct sowing is obvious and the technique has the potential for further cost reduction. In addition to cost, other important considerations will include the long term ability of spoil to support high native tree stocking rates, the need for maintenance fertilizer applications and the aesthetic requirements of mine managers.

7.8.3 Broadacre Field Trial 2. C.S.R. Lemington Colliery

7.8.3.1 Objective

To examine the effect of two substrates at C.S.R. Lemington Colliery on the germination and early growth of five directly sown native tree species.

7.8.3.2. Results

Plates 7.3 and 7.4 show Topdressing (13) and Sandstone (14) 12 months after sowing.

Total and individual species results for trees per hectare, composition per cent, germination per cent, average height and average basal area for Topdressing (13) and Sandstone (14) are shown in Table 7.15.

Plate 7.3 Directly sown native tree species growing on Topdressing (13) at C.S.R. Lemington Mine 12 months after sowing. Note concentration of trees along rip lines.

Plate 7.4 Directly sown native tree species growing on Overburden (14) at C.S.R. Lemington Mine 12 months after sowing.

Table 7.15 Effect of two substrates at C.S.R. Lemington Colliery on stocking rate, composition per cent, average height (m) and average basal area (cm^2) for seven native tree species 12 months after sowing.

SUBSTRATE	SPECIES	VARIABLE				
		Stocking rate (Trees ha^{-1})	Composition %	Germination %	Average height(m)±SE	Average Basal Area (cm^2)±SE
Topdressing (13)	*A. saligna*	3,587	40.5	18.4	0.86(A)±0.02	2.10(A)±0.15
	C. glauca	0	0.0	0.0	0.00	0.00
	E. cladocalyx	3,880	43.8	4.1	0.55(BD)±0.02	0.84(BC)±0.06
	E. crebra	213	2.4	0.1	0.58(BD)±0.07	1.06(B)±0.38
	E. gomphocephala	187	2.2	0.3	0.33(C)±0.03	0.37(C)±0.10
	E. maculata	640	7.2	0.4	0.44(CD)±0.04	0.36(C)±0.06
	E. tereticornis	347	3.9	0.1	0.42(CD)±0.06	0.44(BC)±0.20
	TOTAL/AVERAGE	8,853	100	0.9	0.66	1.29±0.07
Sandstone (14)	*A. saligna*	2,020	39.7	10.4	0.93(A)±0.04	4.28(A)±0.42
	C. glauca	10	0.2	*	0.60(BC)±0.06	0.20(D)±0.00
	E. cladocalyx	2,480	48.8	2.6	0.96(A)±0.03	4.13(A)±0.28
	E. crebra	10	0.2	*	0.40(D)±0.00	0.64(C)±0.0
	E. gomphocephala	50	1.0	0.1	0.72(ABC)±0.12	3.63(A)±1.04
	E. maculata	420	8.3	0.3	0.59(C)±0.06	1.29(B)±0.23
	E. tereticornis	90	1.8	*	0.71(ABC)±0.18	3.36(AB)±1.63
	TOTAL/AVERAGE	5,080	100	0.5	0.91	3.92

Note : For each substrate height and basal area values with the same latter are not significantly different for $P \leq 0.05$.

* Less than 0.1%

7.8.3.3. Discussion

Differences in germination per cent, trees per hectare and average height between substrates at C.S.R. Lemington Colliery were much less pronounced than differences between the same variables for the two substrates at Bloomfield Colliery in broadacre field trial 1. This is despite lower average annual rainfall and greater temperature extremes at C.S.R. Lemington Colliery in the upper Hunter Valley (Tables 3.1 and 3.2) and the expectation that extremes of climate could be expected to accentuate physical differences between substrates, particularly plant water availability. The results suggest that the physical and chemical characteristics of substrates at C.S.R. Lemington Colliery were more alike than for substrates at Bloomfield Colliery.

The superior growth of seedlings on Sandstone (14) in this experiment was consistent with good growth of trees observed on a wide range of overburden and interburden materials in this study. The need to consider substrates other than traditional pre-stripped topdressing material for surface use, may have advantages both for plant growth and economically. At most mines pre-stripping and respreading topdressing material to a depth of approximately 20 cm costs up to approximately \$4,500 ha-1 (Bailey 1987). This cost must be justified by the inherent benefit of using this material. This implies early identification of suitable alternatives in the rehabilitation planning process, if topdressing material is not used. The adequate growth of native tree seedlings on a wide range of substrates is supported by the absence of limiting chemical conditions found in this study. There was little evidence from tests undertaken on surface materials in this study to support the relatively high incidence of overburden material with unfavourable sodic (67% of all overburden materials tested) and saline (16%) properties reported by the SPCC (1983) for overburden material from the Wittingham seam. There was no evidence in this study to suggest that the high pH of some substrates restricted growth. The results suggest that the critical upper limit of pH 8.5 shown in Table 5.1 may be too low for the native species tested.

The main advantage of Topdressing (13) in this experiment was the superior germination per cent of most species. This may have related to the acidic nature of Topdressing (13) (pH 5.0) and the alkaline nature of Sandstone (14) (pH 8.6). Extremes in pH have been thought to affect natural regeneration within the Hunter Valley (Reynolds 1983) with species such as *E. crebra* showing a strong preference for acidic spoil. However, the combined results of glasshouse experiments 1 and 3 suggested that pH variation did not affect germination, although the pH range in both cases was less than in this trial. A wider range of species is important if future tree stands are not to be dominated by a small range of larger seeded species, such as *A. saligna, E. cladocalyx* and, to a lesser degree, *E. maculata*. However, although a wider variety of species on Topdressing (13) after 12 months bodes well for greater long term stand diversity, it does not guarantee such a result. Long term monitoring of stand development will be necessary to assess the suitability of original species and rates. There is also little experience from which to assess whether overall stand development will be impeded on any of the substrates in the longer term due to competition resulting from high stocking rates.

The low stocking rate of some species suggest that supplementary planting may be necessary to ensure their presence. This is particularly true for Sandstone (14). On Sandstone (14) the stocking density of sown *C. glauca, E. crebra, E. gomphocephala* and *E. tereticornis* after 12 months was considered inadequate and supplementary planting of these species is recommended. On Topdressing (13) supplementary planting of *C. glauca* would be necessary. Irving (1986) suggests the decision to plant *Casuarina* should be delayed as he did not record substantial number of *Allocasuarina* and *Casuarina* on Rhodes grass plots until 41 months. However, delayed planting of seedlings into established stands is rarely successful due to strong competition from established trees. Supplementary enrichment planting must occur close to sowing time. Broadacre field trial 1 indicated that planted trees grow faster than sown seedlings after 12 months. This advantage should help ensure the long term survival of planted species in the stand and hence justify the high cost of planting. The need to increase species diversity through supplementary planting is another coşt and must be considered when assessing surface material suitability.